SuperTruck – Development and Demonstration of a Fuel-Efficient Class 8 Tractor & Trailer

Engine Systems

DOE Contract: DE-EE0003303

NETL Project Officer: Ralph Nine

DOE Project Manager: Roland Gravel

Navistar Principal Investigator: Russ Zukouski

DOE MERIT REVIEW

06/09/2016

Project ID: ACE059

Program Overview

Timeline

Project Start:	October 2010
Project End:	Sept 2016
% Complete:	91%

Partners

Navistar	Principal Investigator, Vehicle Systems Integrator Controls Systems, Engine & Vehicle Testing
Bosch	Fuel Systems
Wabash	Trailer Technologies
ANL	Dual Fuel Engine testing, simulation & evaluation
LLNL	Aerodynamic CFD

Barriers

- Achieving 50% freight efficiency while balancing Voice of Customer Needs
- Alignment with business needs
- Reducing tractor weight while adding new systems

Budget

Total Funding:	$76,178,386
DOE:	$35,754,460
Prime:	$40,423,926
Funding FY2015	$8,965,646
Funding for FY2016	$4,896,000

Objectives and Relevance

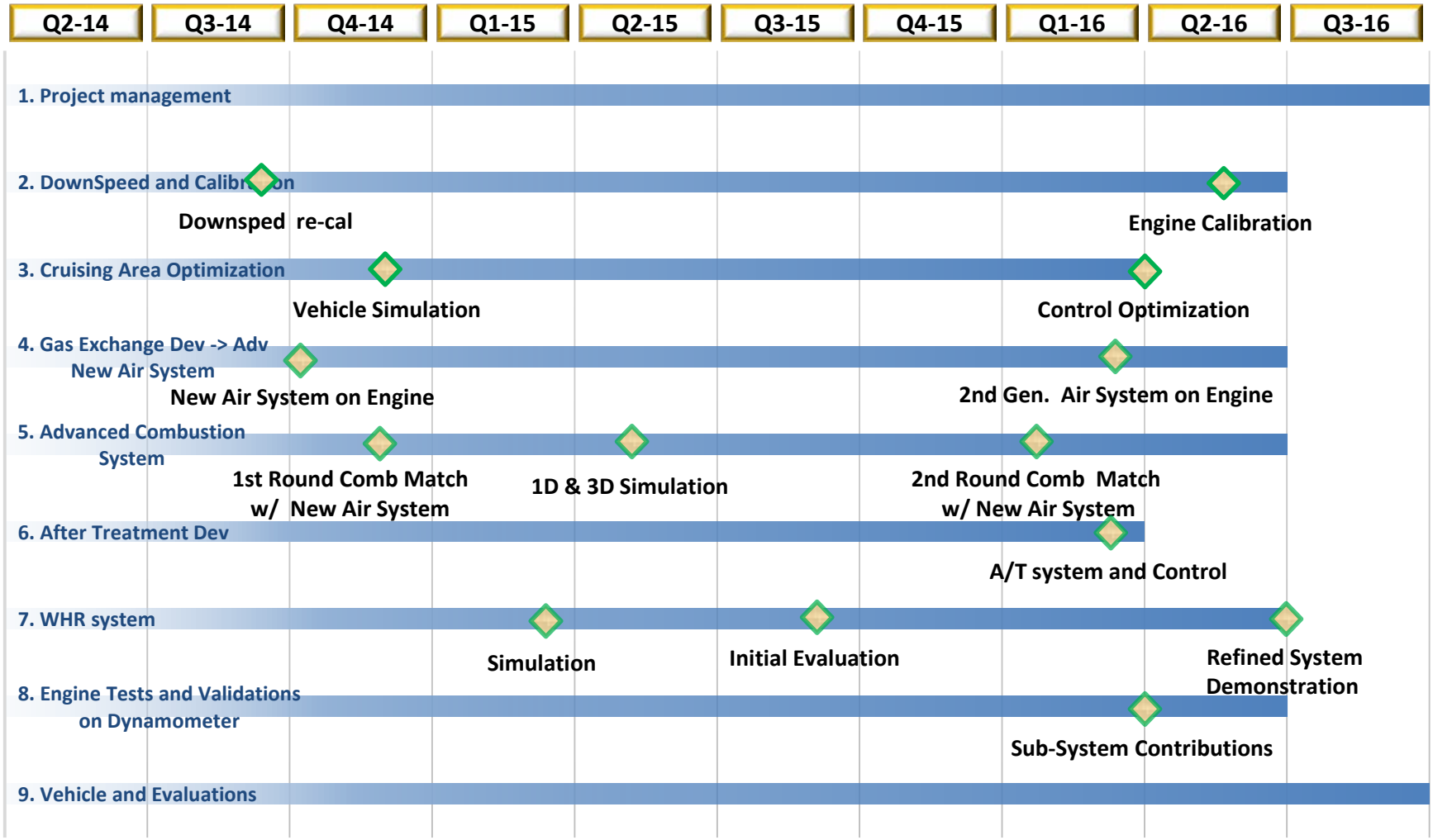
Goals and Objectives

1. Demonstrate 50% improvement in freight efficiency
   20% through Engine technologies
   30% through Vehicle technologies
2. Demonstrate 50% BTE on Engine Dynamometer
3. Demonstrate technical pathway towards 55% BTE

Relevance

- ✓ Provide a realistic technology demonstrator to reduce petroleum consumption in the truck market:
  - → Engine technologies closely worked with business requirements
  - → Focus on packaging and customer interface (key in the case of Waste Heat Recovery)
- ✓ Work with Partners to develop robust products for commercial integration:
  - → High efficiency common rail Fuel Injection System (FIS) (BOSCH) for advanced combustion
  - → Advanced base engine technologies for friction reduction
  - → Worked with Argonne National Labs to provide technical path for alternative fuels and clean combustion systems
- ✓ Work with Collaborators…

Timing / Milestones



Vehicle Partnerships and Completed tasks

	12-Apr	12-Oct	14-Apr	15-APR	16-APR	16-Sep
	Phase I		Phase II	Phase III		Phase IIII - V
Navistar	*Vehicle systems integrator* *Control Systems* *Base Engine*		*Concept technologies chosen* *48.3% BTE achieved* *Load biasing evaluated* *Material procured for Mule build* *Engine Design* *Controls deployment*	*T3 Vehicle achieved 70% FE* *48.9% BTE achieved* *Load biasing concluded in final build* *Material procured for Mule build* *Engine Design* *Controls deployment*		***50% + FE***
Wabash National	*Trailer Technologies*	***PAUSE***	*Trailer Design*	*Trailer and system built*		***50% + FE***
BOSCH	*Fuel Systems*		*Adv comb with FIS* *strategies*	*Adv comb with FIS optimization complete* *WHR system developed*		***50+ BTE Path*** ***55% BTE***
LLNL	*Computational Fluid Dynamics*		*Computational Fluid Dynamics*	*Speed form complete* *wind tunnel testing* Final body shape in procurement		***50% + FE***
ANL	*Engine Design* *Controls deployment* *Fuel Reactivity testing*		*VVA* *1D/3D simulations* *Reduction of Parasitic* *Fuel Reactivity testing*	*VVA evaluated* *1D/3D simulations* *Reduction of Parasitic demonstrated* *Fuel Reactivity testing in final stage*		***50+ BTE Path*** ***55% BTE***

FE = Freight Efficiency (ton-miles/gal)

Engine Collaborators & Completed Tasks

12-Oct	14-Apr	15-Apr	16-Apr	16-Sep
	Phase II	Phase III		Phase III-IV
PAUSE	Mahle ✓ *Adv. Power Cyl. Concepts* ✓ *Heat Exchangers*	✓ *Pwr cyl optimization* ✓ *WHR system and components re-defined by simulation*		***55% BTE Demo***
	Borg Warner ✓ *Turbos / Air Systems*	✓ *Optimized turbocharger system*		***50% BTE Demo***
	Jacobs Vehicle Systems ✓ *Variable Valve Actuation*	✓ *Pumping work reduction for specific operating modes*		***55% BTE Path***
	Philos Technology ✓ *Surface Treatment Evaluation*			*55% BTE Path*
	Federal Mogul ✓ *Accessory prove out* ✓ *Kit procurement*	✓ *Friction Engine Testing*		***55% BTE Path***
	C.E.S.	✓ *High Efficiency Aftertreatment*		***50% BTE Demo***
	Adiabatics, Inc.	✓ *Advanced Thermal Mgmt.* ✓ *Thermal Barrier Coating*		***55% BTE Path***

Barriers and Technology Roadmap

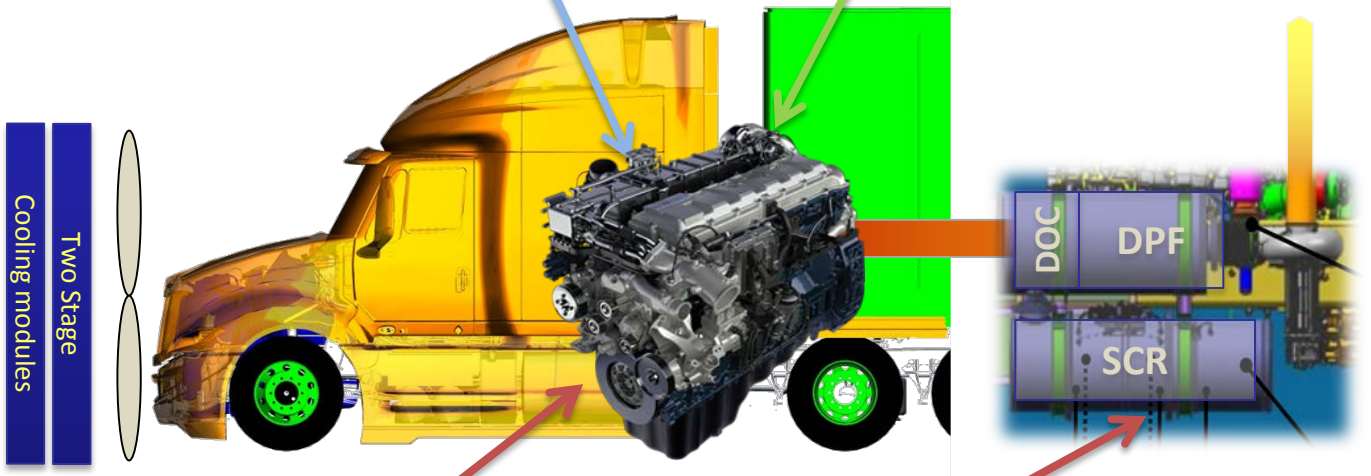
Keys: ✓ high confidence to contain
✸ working on improving solution

System	Barriers (challenges)	Technology Roadmap
Engine & Vehicle	• *Cost effective* • *Robust (controls, durable)* • *Reduced weight*	*Rely on analysis to select technology* ✓
Engine	• *High combustion efficiency* • *High efficiency A/T System* • *Air system with minimum losses*	*Improve FIS and combustion match* ✓ *Advanced combustion regimes* ✓ *Improve gas exchange efficiency* ✓ *Advanced aftertreatment* ✸
Engine	• *Modest bottoming cycle efficiency* • *Parasitic reduction* • *WHR system*	*Advanced designs* ✓ *Close collaboration with suppliers for new technologies* ✓ *Optimum integration to engine* ✓
Engine	• *Non optimum fuel formulation* • *Optimal dual fuel reactivity*	*Introduce reactivity control* ✓ *Understanding of chemical kinetics* ✸

Approach – Technology Selection

2. Air System
- VG turbo with improved Efficiency
- High flow cylinder head

3. Friction-Accessories
- VWP
- Power Cylinder Components
- Reduction of pumping loss



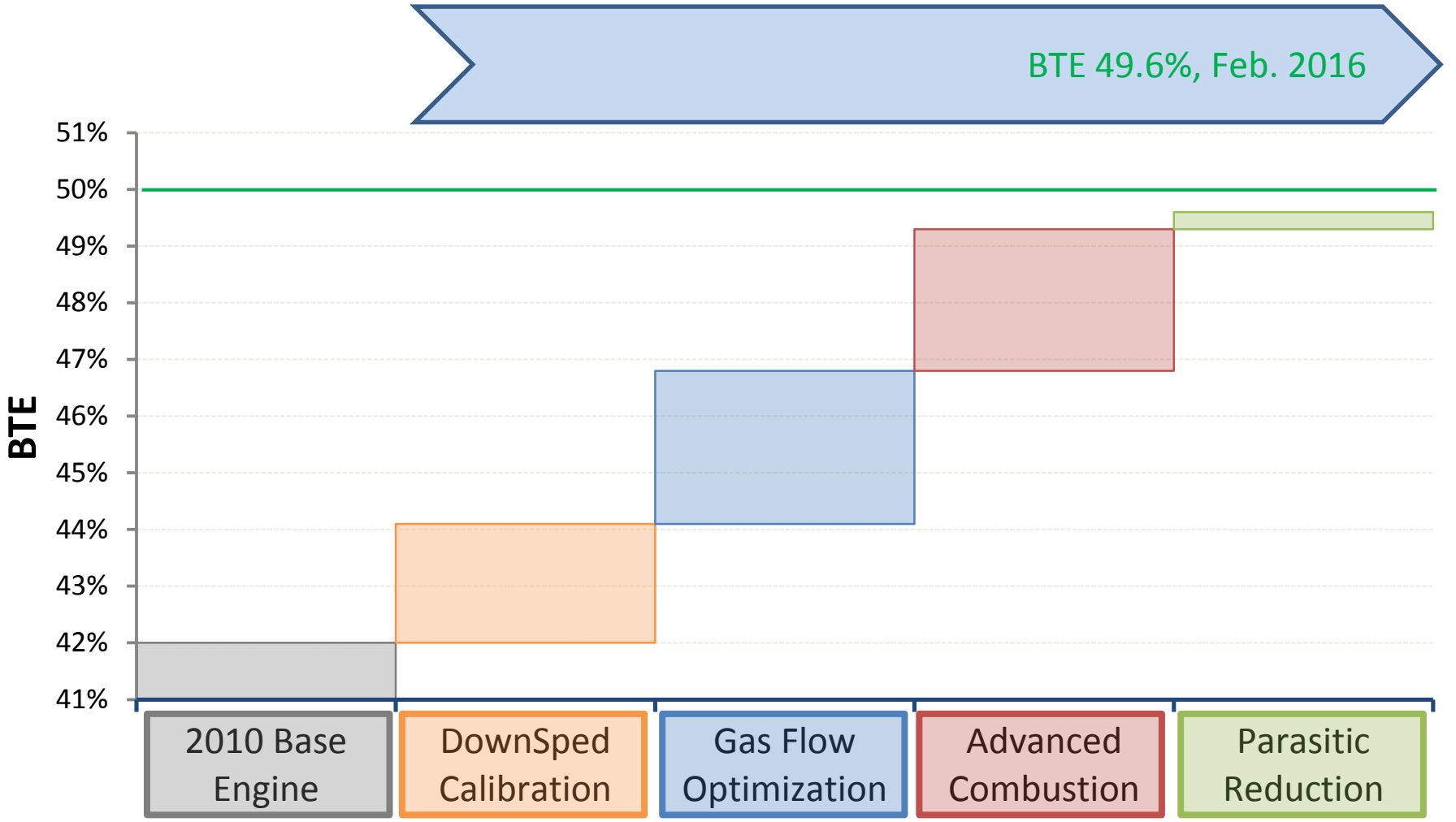
5. WHR
- ORC system

1. Combustion
- New combustion chamber
- Bowl-optimization
- Increased PCP
- Thermal management

4. Aftertreatment
- DOC/DPF + SCR
- Close coupled
- Hi efficiency
- Low DP

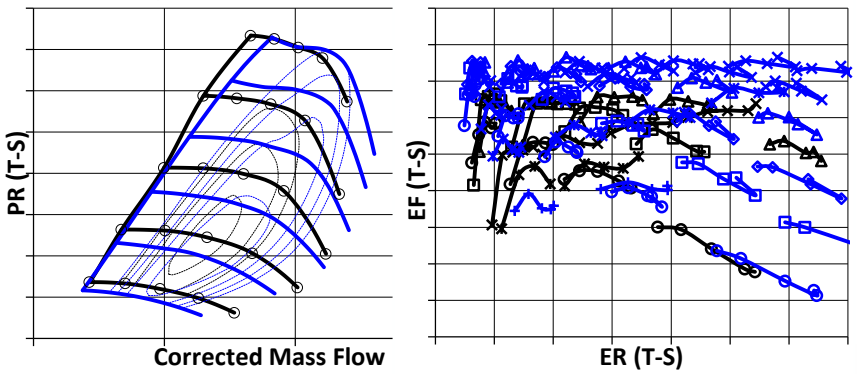
Optimize Integration Criteria
- Efficiency gain (BTE)
- Weight (Ton-mile/gallon)

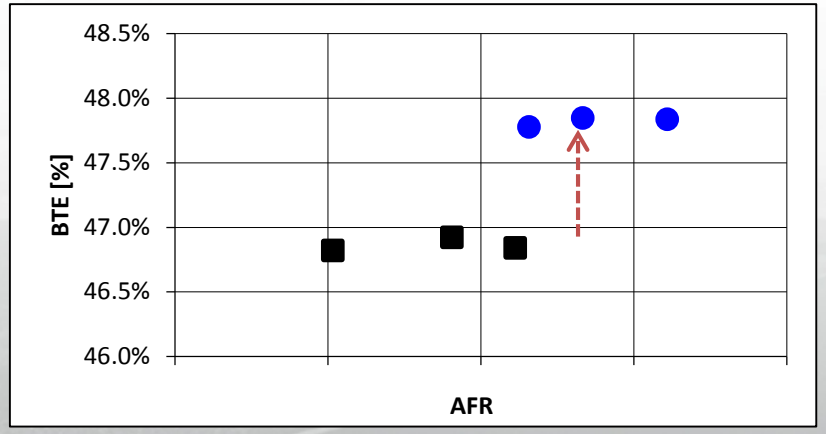
Accomplishments – Engine Dyno 49.6% BTE



Accomplishments – Air System / VVA / RSD

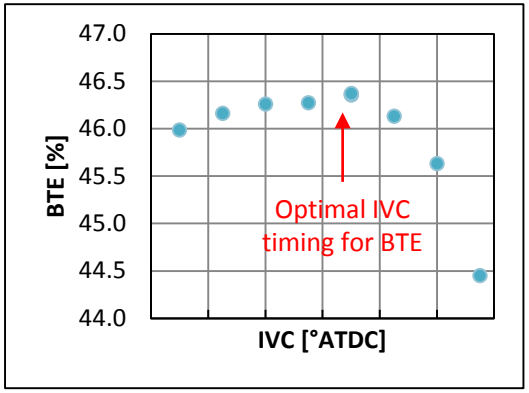
- High Efficiency Turbocharger
  - Compressor Map
  - Turbine Map



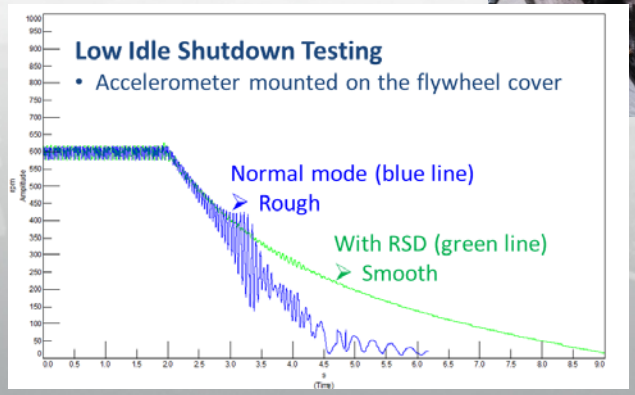


Successful implementation of turbo system technology to test engine

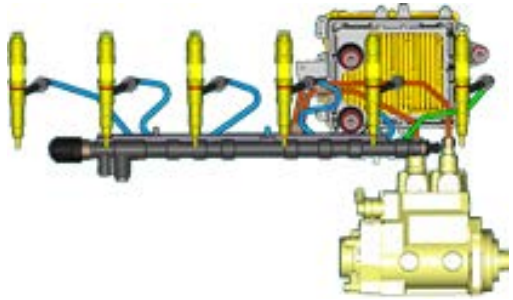
- VVA installation on the test engine at ANL:

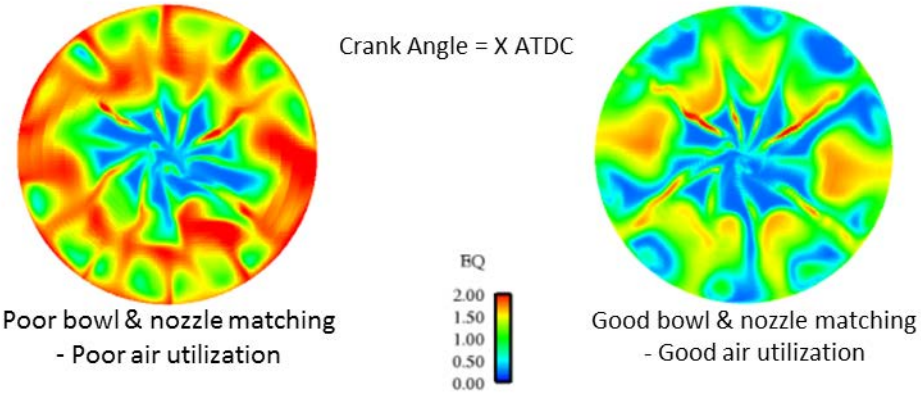


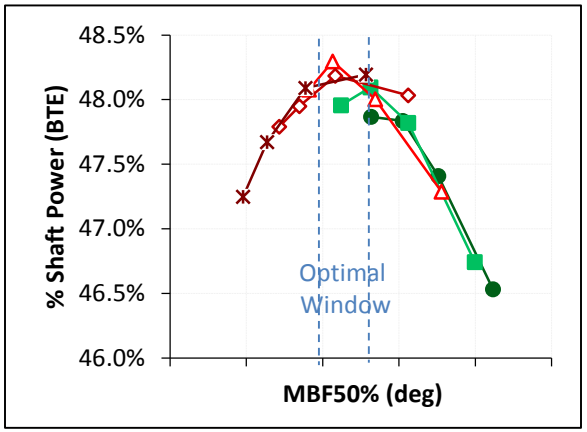
- RSD (Rocker Stop Device)
  - A/T thermal management
  - Stop/Go operation

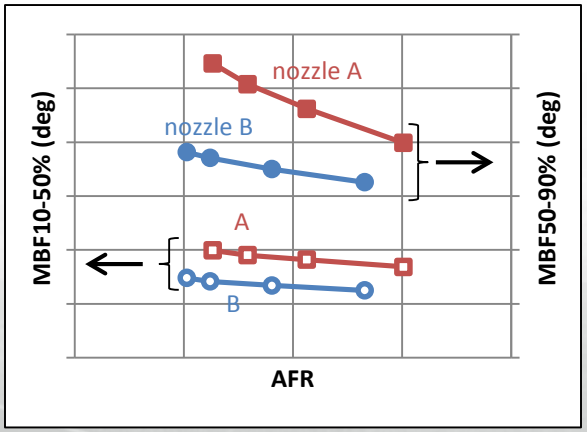


Accomplishments – Advanced Combustion







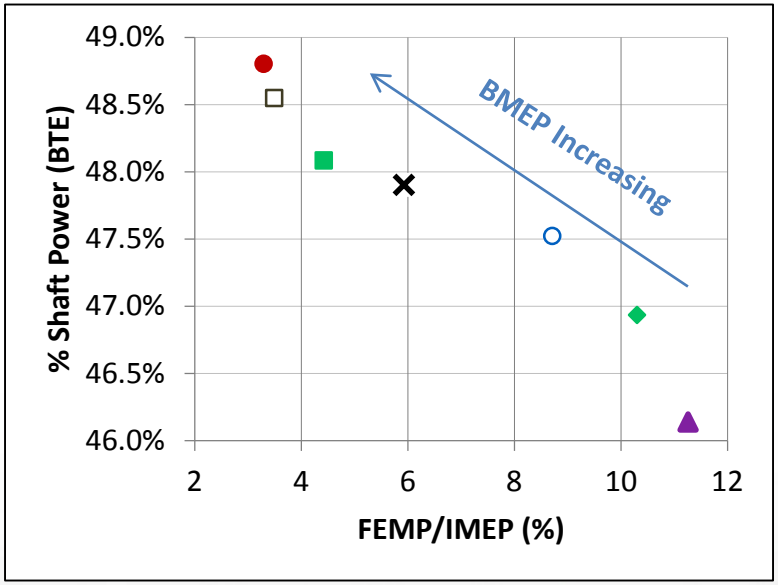


Combustion Optimization:

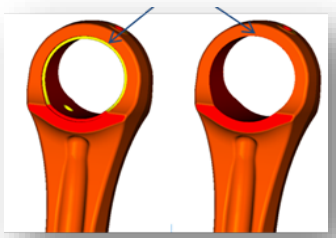
- Compression ratio (CR),
- Combustion chamber and matching fuel injection strategies,
- Combustion phasing

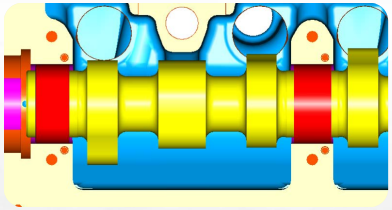
Good air utilization will improve the 2nd half of diesel combustion, MBF50-90%, faster diffusion combustion.

Accomplishments – Reduction of Parasitic Losses

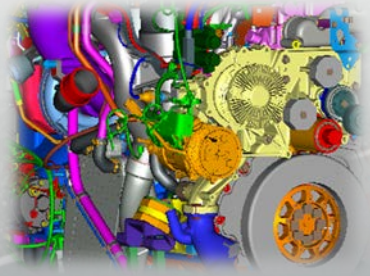


Power Cylinder

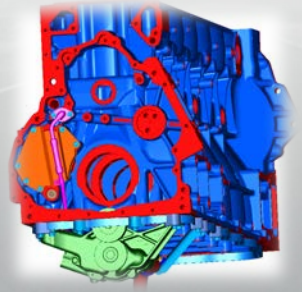




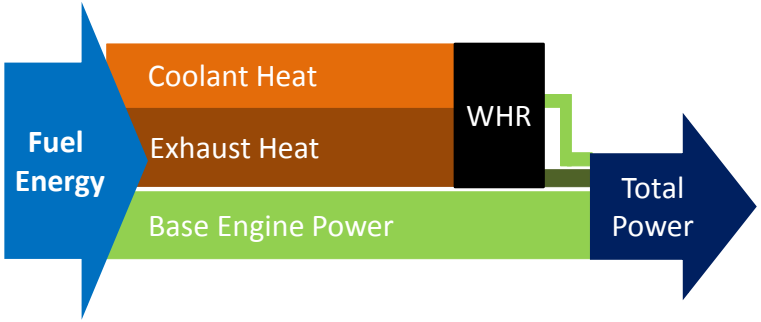
Cooling System

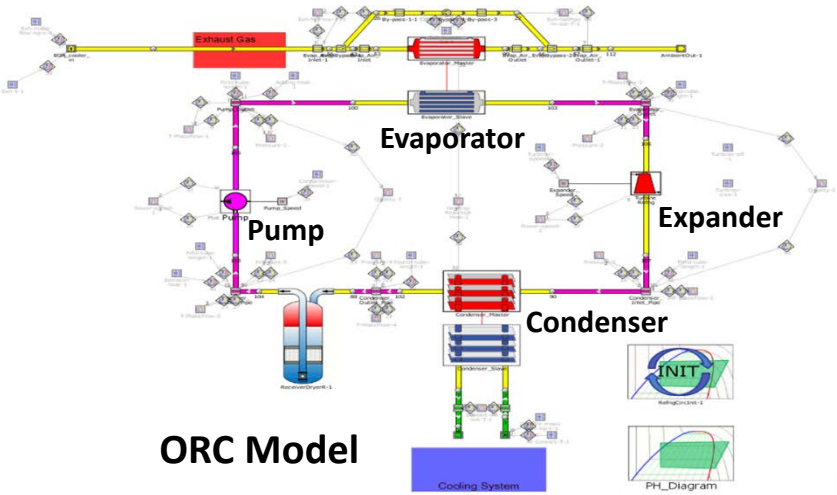


Lube + Cooling



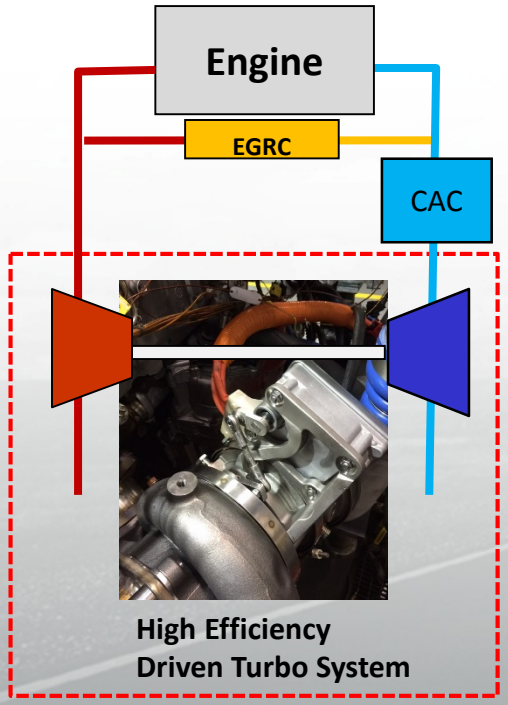
Accomplishments – Evaluation of WHR Strategy

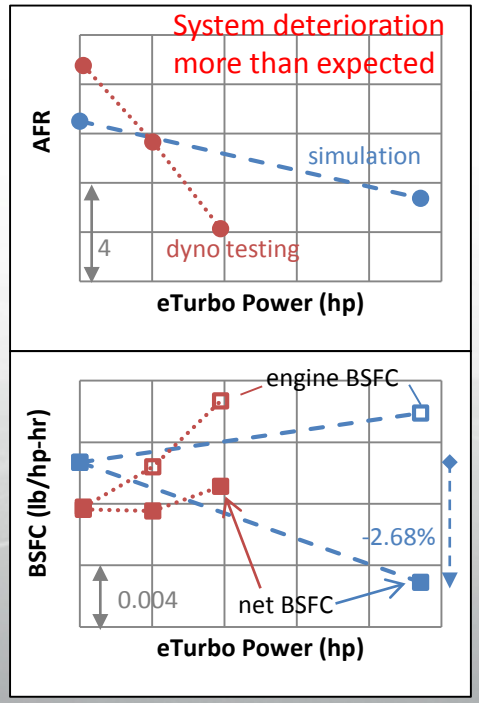




ORC Model

✓ eTurbo evaluation

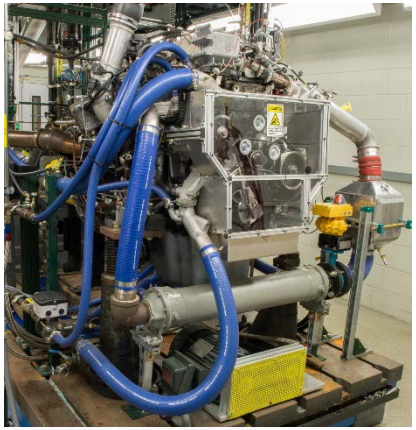


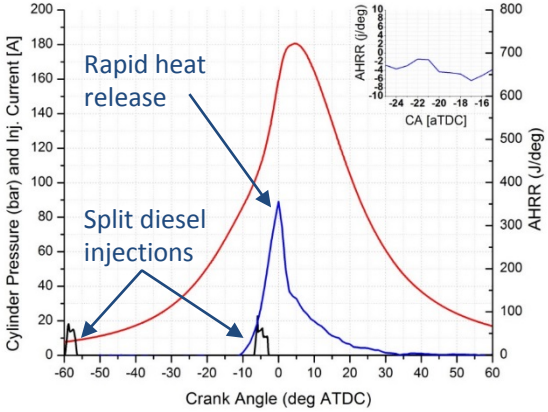


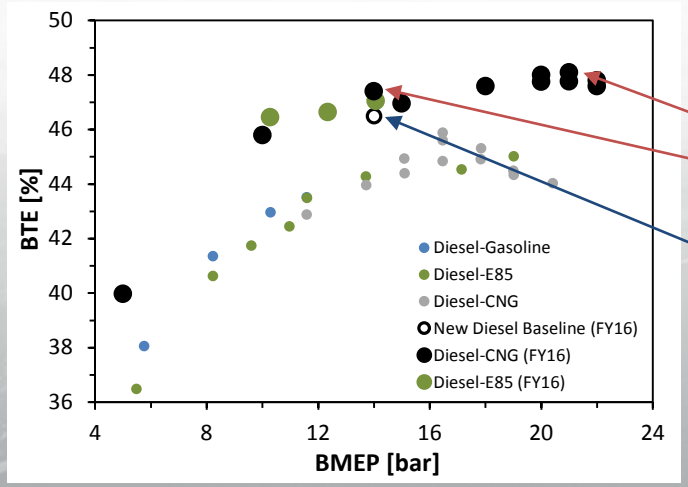
✓ Prototype system in test cell.

Accomplishments – 55% BTE Pathway

➢ Dual-fuel evaluation



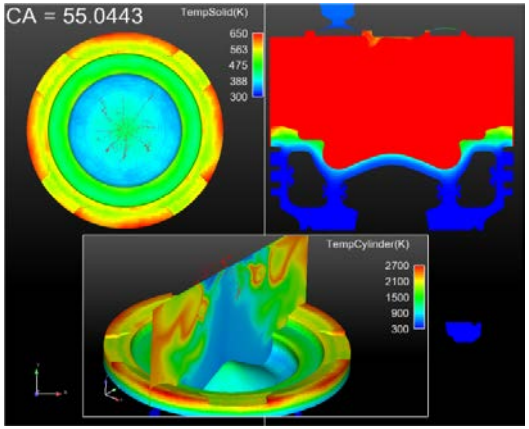




Diesel-CNG best points
48.1% at 20 bar
47.4% at 14 bar

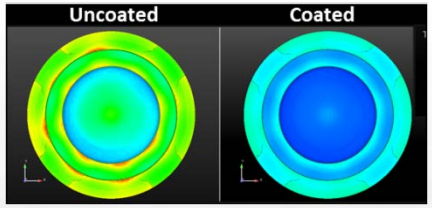
Diesel only baseline
46.5% % at 14 bar

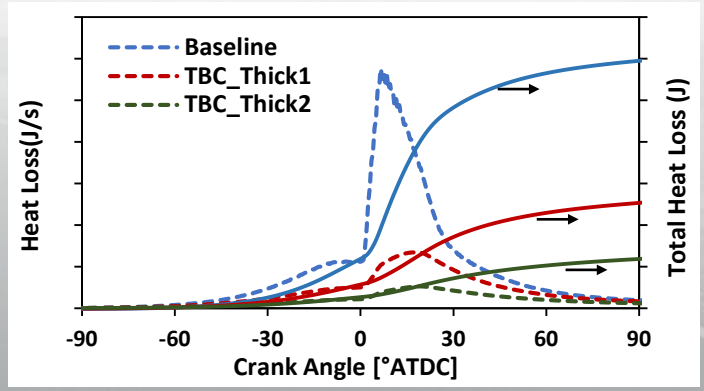
➢ In-cylinder heat transfer modeling



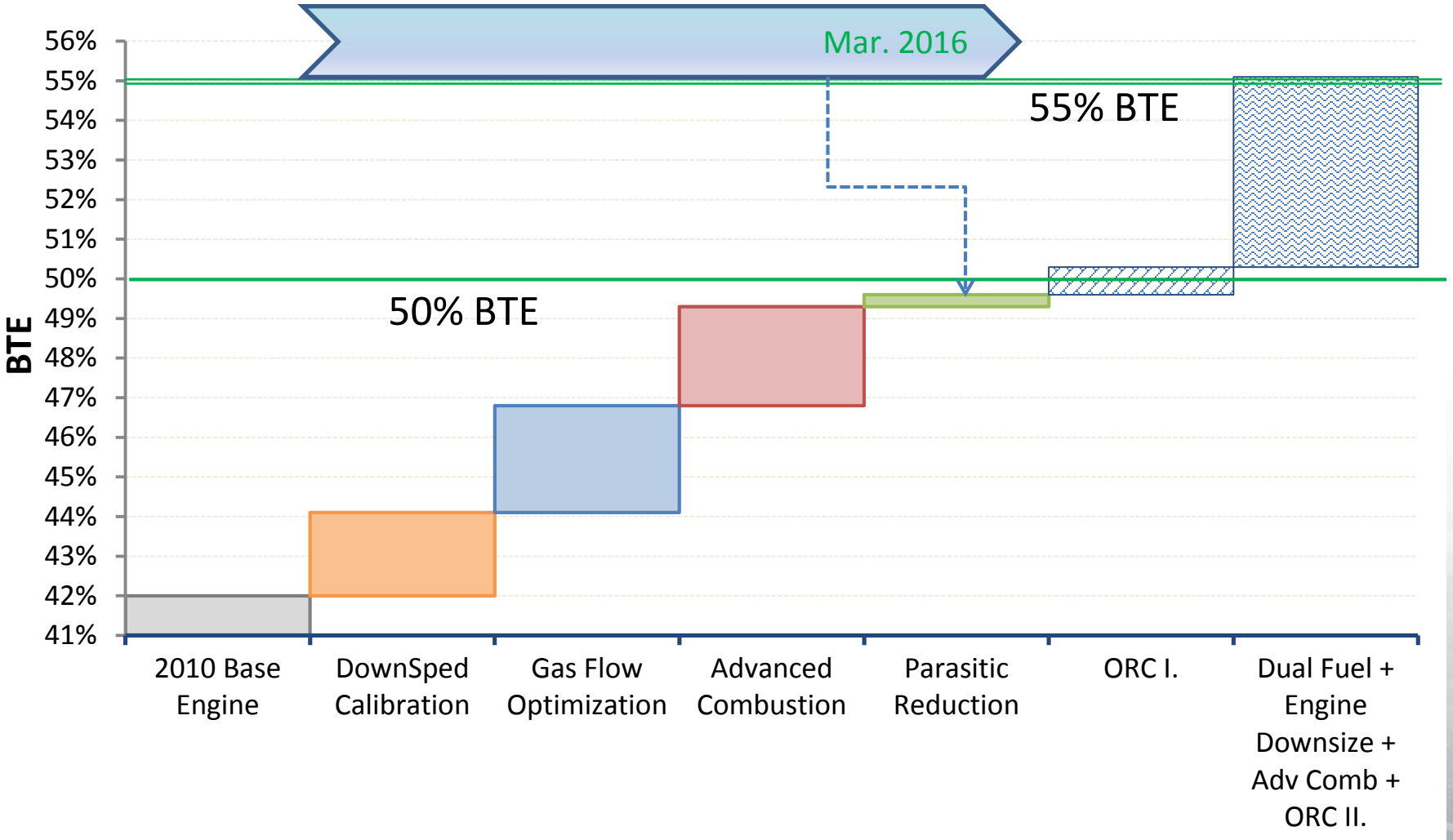
- Conjugate Heat Transfer (CHT)

- Thermal Barrier Coating (TBC)





Future Work – Moving Forward



Wrap-up Work

- ✓ **ORC system optimization**
- ✓ **Aftertreatment thermal management**
- ✓ **Control Strategy optimization**
- ✓ **System Integration/packaging**
- ✓ **High efficiency air system optimization**
- ✓ **In cylinder thermal management**
- ✓ **Reactivity studies performed with gasoline and alcohol fuel**

Technologies/methods utilized to achieve 50% BTE

- ✓ **On engine combustion:**
  - Newly designed combustion chambers and system match
  - Investigation and understanding combustion phasing
  - Extended peak cylinder pressure capability
- ✓ **Engine Downsped**
  - Re-cal and optimization
- ✓ **Reduction of Parasitic Losses**
  - Base components, lube and cooling, were updated raising BTE
  - Power cylinder components were procured and evaluated
- ✓ **WHR system**
  - Simulation to define ORC system components
  - Prototype system was assembled for testing and evaluation.

Advanced 55% BTE technical path

- ✓ **Reactivity studies performed with gasoline and alcohol fuels**
  - High engine efficiencies were compatible with very reduced engine emissions
  - Study will continue with enabling features recently added VVA system, such as high compression ratio, new combustion system
- ✓ **Both 1D and 3D simulations are used for technical feasibility study**